The Prevalence and Costs of Scour Damage at River Bridges in South Africa

M.E. Cunninghame [1], N.P. Armitage [2]

[1] MSc(Eng) Student, Department of Civil Engineering, University of Cape Town, Rondebosch, South Africa
[2] Associate Professor, Department of Civil Engineering, University of Cape Town, Rondebosch, South Africa

ABSTRACT

Scouring of riverbeds at engineering structures is a major cause of structural damage to bridges and fluvial structures in South Africa. The types of scour posing the greatest threat to the integrity of river bridges in South Africa were identified in a desk and field study of 121 distressed provincial road bridges and estimates of the average annual costs of scour damage were made. Scour damage is evident at approximately 24 % of provincial road-river bridges in South Africa and the most prevalent mechanisms of scour damage are as a result of local and constriction scour. Cost data for current maintenance activities and documentation of scour damage in major past floods indicate that the annual average financial cost of scour damage occurring in South Africa is at least R24 million. Inclusion of the economic costs associated with failure of important river crossings is expected to inflate the annual average cost of scour damage significantly.

Keywords: *Scour damage, bridge failure, field survey, South Africa, scour damage cost.*

1 INTRODUCTION

The failure of river crossings and engineering structures such as bridges, weirs and other hydraulic structures in rivers due to scour damage has resulted in substantial financial and economic losses in flood-affected regions. The well-known failure of the John Ross Bridge over the Tugela River during 1987 floods in Natal was caused by scour which undermined the bridge pier foundations (Van Bladeren & Burger, 1989). Vehicles which would normally use the bridge had to travel significant additional distances. Such failures do not, however, occur in isolation as demonstrated during these floods by the 120 bridges in Natal that were destroyed or severely damaged. Substantial losses were felt by the local economy. There is a need for better understanding of scouring processes to prevent, or at least reduce the severity of, such events in the future.

This paper presents the findings of an investigation into the following:

- The prevalence of scour as a mechanism causing damage to, and failure of, bridges at river crossings in South Africa.
- The predominant type of scouring which currently occurs at South African river bridges.
- The approximate average annual cost of the scour damage which occurs at road bridges in South Africa.

The findings of this study justify further investigations into river scour and those scouring mechanisms which pose the greatest threat to river bridges in South Africa.

To achieve the objectives listed above, the following approach was adopted: Documentation of major floods in South Africa, and particularly KwaZulu Natal, over the past five decades was reviewed. A field and desk study of 121 bridges currently experiencing scour problems was then undertaken to determine the prevalence of different types of scour. Analyses of the nature of the damage were conducted and estimates of the associated repair costs were made. The study focused on scour around piers and abutments supporting road bridges although scour at the foundations of pipe and rail bridges and around various hydraulic structures were also noted on occasion. Emphasis was placed on the assessment of those scouring mechanisms such as general, local and constriction scour which attack bridge foundations directly. Erosion of earth embankment dams and berms was not addressed.

A review of scour damage occurring in extreme floods which occurred in South Africa in the past is presented as background to the study in Section 2. The methods adopted for investigation and data analysis are then discussed in Section 3. Findings relating to the nature and costs of scour damage in South Africa are given in Section 4. Conclusions and recommendations for future study are finally presented in Sections 5 and 6 respectively.

2 HISTORICAL RECORDS OF SCOUR DAMAGE

2.1 Recurrence of floods and scour damage at bridges

Advances in flood hydrology are gradually improving prediction of the magnitude and frequency of flooding in South Africa. Historical records indicate, however, that extensive damage to engineering structures such as weirs and river bridges has continued in spite of improved flood prediction. Often a single structure has been damaged repeatedly by major floods over several decades. A better understanding of the processes causing damage and structural failure and improved design methods are thus needed to prevent recurrence of damage of the extent and severity experienced in past flood events.

Records of scour-related bridge failure in Natal rivers date back to 1868, when floods caused the failure of the iron plate girder Queens Bridge over the Umgeni River near Durban. During the 1959 floods in Natal, one pier on the Lovu River bridge sank by 2.74 m and three bridge spans were destroyed. Once again in March 1976, one pier settled by 1.83 m. Damage to bridges on the Natal South Coast during the 1976 floods was estimated at R50 million (R1,020 million in 2005 values). Scouring around piers and piles was noted as one of the most common causes of bridge failure during the 1987 Natal floods (Van Bladeren & Burger, 1989). A total of 130 bridges were destroyed or severely damaged during these floods including the John Ross / N2 Bridge over the Tugela River. Change in a river's course and lateral erosion also led to the failure of a number of bridges and gauging weirs during these floods. For example, the approaches to the Edendale bridge over the Msunduse River and to the N2 bridge over the Mdloti River were badly eroded.

The N1 route from Cape Town to Beit Bridge has been "seriously disrupted" by floods on five occasions in the past 42 years (Alexander, 2000). Approximately 200 bridges and other drainage structures were washed away or severely damaged during floods in the Limpopo Province in 2000. The value of damage to provincial roads and bridges in the province was estimated at R1,269 million (R2,120 million, 2005) (Chabane *et al.*, 2000). This excludes extensive damage to local streets and drainage structures falling under local government authorities. Extensive damage to infrastructure and disruption of economic activity also occurred in Mpumalanga. Yet, in a discussion of these floods, Van Bladeren & Van der Spuy (2000) list twelve previous flood events in the region, dating back to 1909, which caused damage of comparable magnitude to that experienced in the 2000 floods indicating that some important lessons have not been learnt.

Scour damage to bridge foundations is certainly not limited to structures in rural areas. Urban streams receiving fast flowing water from impermeable surfaces, concrete pipes and lined channels also encounter scour problems. During the February 2000 floods, bridges in many golf courses in Gauteng were affected by flood damage as these rivers are often not canalised to enhance their aesthetic appeal. For example, foundations of bridge piers and abutments in the Jukskei River at the Dainfern Golf Course were undercut, bridge approaches were washed away, and sediment deposits left on the fairways (Arup, 2000).

Scour is difficult to detect and the maximum scour depths attained under peak flood conditions cannot be measured with ease. Scour at the Pondoland Bridge on the Mzimvubu River at Port St Johns after the 1978 floods, caused the failure of one pier and the collapse of two spans. The scour depth at the bridge was estimated at 19.5 m by depth soundings but had diminished to 0.4 m two years later (Van Bladeren, 1992). Van Bladeren & Burger (1989) note that time scales for scour are short. Sedimentation in the scour holes may occur within a few hours after the flood peak thereby concealing the maximum scour depth attained.

Although scour damage at provincial road bridges is the focus of this study, extensive scour damage at hydraulic structures such as weirs also occurs. Damage to the flow gauging network of the Department of Water Affairs and Forestry (DWAF) during the 2000 floods in the north of the country was estimated at R32 million (R53 million, 2005). In addition, invaluable and irretrievable flow data was lost. Gauging weirs were frequently outflanked and recording instruments washed away. Scour may often have been responsible for the outflanking of the concrete weirs and undermining recording towers but since recording stations may be partially or entirely submerged when failure occurs, the exact cause of failure is often difficult to establish. In the Natal floods of 1987, damage reports were prepared for 68 gauging stations of which 34% were destroyed and a further 18% suffered structural damage. The total damage to the provincial flow gauging network was estimated at R1.2 million (R 6.7 million, 2005) which was equal to the total annual budget of the Natal Directorate of Hydrology for that year (Van Bladeren & Burger, 1989).

2.2 Disruption of economic activity

Substantial economic losses may result from transport routes and communication links which are lost due to floods. During the 2000 floods, some routes in the Northern Province carrying in excess of 4000 vehicles per day were cut off for long periods of time. The temporary bypasses were vulnerable to smaller floods occurring after the main event and were sometimes unsuitable for use by heavy vehicles. Alternative routes had to be found for rail transport and an additional 600 km had to be travelled on some routes.

Concrete weirs forming part of the irrigation network for sugar cane production in the Komatipoort – Malelane area also failed in the 2000 floods. Nortje (2000) indicated that this would have severe consequences for the farming community for a number of years and suggested undermining of the weirs' foundations as a likely failure mechanism.

2.3 Interruption of engineering services

Pipelines attached to road and rail bridges are also affected by damage sustained by bridges. Basic water supply to rural communities, particularly in the Northern Province and Mpumalanga, was severely disrupted by the February 2000 floods. Damage to weirs, pump stations and pipelines affected water supply to more than 2.1 million of the 3.5 million people normally served by this infrastructure (Muller, 2000). Damage sustained by many bridges also resulted in damage to pipelines supported by these structures.

2.4 Importance of scour in structural failure and the need for investigations into damage

The prevalence of scour as a mechanism for structural failure has been noted in several studies of large flood events in South Africa. In an investigation into January 1981 floods in the South Western Cape, Kovács (undated) stated that the erosion of soil and subsequent deposition of sediments is probably the most prevalent form of flood damage affecting the drier areas of South Africa. Scouring around piers and piles was noted as one of the most common causes of bridge failure during the 1987 Natal floods (Van Bladeren & Burger, 1989). A comprehensive study of bridge failures resulting from the floods was carried out, and the cause and mechanism of failure was determined for a total of 31 structures. Scour damage to the bridge foundations or approach embankments was reported at 21 of these sites. Scour undermining bridge foundations directly was identified as the reason for the catastrophic failure of six bridges.

In a review of bridge failure and damage occurring during the 2000 floods in the northern and north-eastern regions of South Africa, Sheasby (2000) reports that most bridges fell into the sub-category of "foundation failure due to scour effects". It was furthermore observed that major bridge crossing failures were predominantly due to scour and that very few structural collapses occurred where piers were properly founded.

In most investigations of major flood events the emphasis has been placed on flood hydrology and relatively few studies have included investigations into the cause of damage to structures in rivers. In the few studies where a damage assessment has formed part of the scope of investigation, scour has been reported as a leading cause of damage (Van Bladeren & Burger, 1989; Sheasby, 2000). Although flood hydrology analyses are essential to improving future flood prediction, investigation into the cause of damage to infrastructure is also extremely important.

3 METHODS OF INVESTIGATION AND DATA ANALYSIS

3.1 Sources of Information

Three sources of information were used to determine the most prevalent types of scour damage and associated annual repair costs: technical reports produced by DWAF documenting major historical flood events, bridge condition information from the provincial Bridge Management Systems (BMSs) and consultants' reports on bridges where special investigations were undertaken.

Technical reports on historical flood events

A Technical Report is produced by DWAF after each major flood event in South Africa. These reports contain primarily hydrological data, but some include an assessment of the damage caused by the flood event. In this study, this information was treated separately from the more current information describing the prevalent types of scour and associated costs obtained from the BMSs. Information presented in the technical reports is generally not detailed enough to accurately determine scour types and costs. Although estimates of the total cost of flood damage are provided in most documentation, the fraction of this cost which may be attributed to scour damage must be estimated. Since the precise cause of the failure of a bridge under extreme flood conditions is often extremely difficult to determine, it was also not generally possible to draw definitive conclusions about the prevalent types of scour from the technical reports.

Current bridge condition information from Bridge Management Systems

The condition of road bridges in most provinces is monitored through Bridge Management Systems (BMSs). These are electronic or hardcopy database systems containing information about all the provincially-managed road bridges. This information is collected during routine bridge inspections and typically includes the following:

- Location, geometry and dimensions of the bridge and a description of the structural system
- The condition of various structural elements of the bridge and waterway, and traffic volumes on the route
- Numeric ratings for the severity and extent of distress exhibited by structural elements
- Estimates of repair costs and an indication of the urgency of these repairs
- Photographs of the bridge in general, specific elements being monitored, and those needing repair

Table 1: Status of Bridge Management Systems in South Africa as at July 2004

Province	BMS Format	Number of Structures in BMS
Eastern Cape	Electronic system linked to GIS	1400
Free State	Hardcopy system with detailed maps	1800
Gauteng	Electronic system	680
KwaZulu Natal	Electronic system	400*
Limpopo Province	Electronic system	800
Northern Cape	Electronic system	500
Western Cape	Electronic system linked to GIS	2200

* Of the 3200 bridges in KwaZulu-Natal, only 400 had been inspected by July 2004.

Information contained in a BMS is collected during routine bridge inspections which take place every five years or as resources permit. The BMS of each province is managed by either the provincial transport or roads authority or appointed consulting engineers. The status of BMSs in South Africa at the time of the study is summarised in Table 1. The state of the BMS in Mpumalanga was not determined. A bridge inventory study was yet to commence in the North-West Province at the time of the study and a BMS would only be set up once the inventory register was complete.

Bridges currently subject to scour damage were identified from the BMSs by, where possible, searching for keywords such as *scour, undermining* and *erosion* or items associated with scour repair such as *backfilling, gabions* and *underpinning*.

Investigative studies and design reports
Investigative reports and bridge design reports produced by consulting engineers for bridges at which particularly severe or recurrent damage has occurred were reviewed upon the recommendation of engineers involved in bridge repairs and BMSs. These reports constituted about 15% of the data collected. No thorough search for such reports was undertaken and thus this source of information is likely to be incomplete.

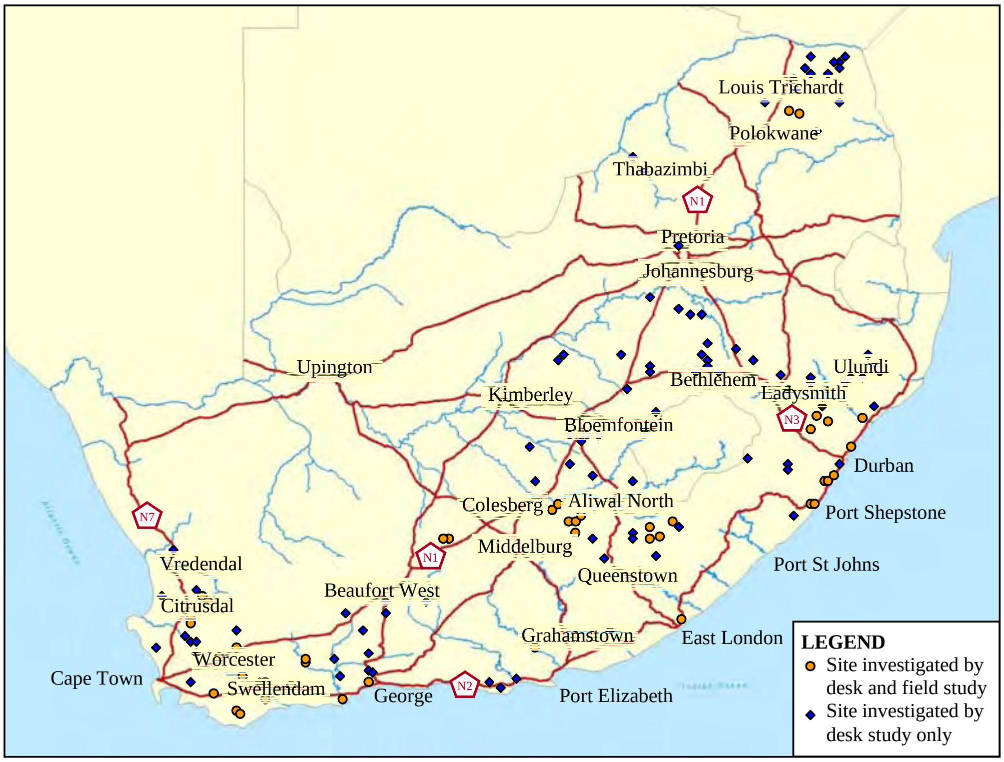

Figure 1: Distribution of survey sites

Table 2: Distribution of survey sites by province

Province	Number of structures investigated		
	Field & desk study	Desk study only	Total
Eastern Cape	20	2	22
Free State	0	31	31
Gauteng	0	3	3
KwaZulu - Natal	15	14	29
Limpopo Province	2	13	15
Mpumalanga	0	0	0
North - West	0	0	0
Northern Cape	1	2	3
Western Cape	18	0	18
Total	**56**	**65**	**121**

3.2 Field Survey

Bridges were chosen for investigation on the basis of the relevance of the nature of distress to the study, the severity of scour damage, and location of the structure. Where priority ratings were employed in the BMS, bridges with higher priority or urgency ratings were selected in preference to others. Structures were otherwise selected on photographs stored in the BMS or upon the recommendation of the person responsible for the system. Selected structures were visited where conveniently located. A total of 121 sites in seven of South Africa's nine provinces were investigated. Visits were made to 56 of these sites and the remaining 65 were investigated by means of a desk study. Two sites were weirs and the remainder provincial road bridges. The distribution of desk and field survey sites is illustrated in Figure 1 and the number of sites investigated by province listed in Table 2.

3.3 Identification of most prevalent scour types

Information obtained from photographs, reports or site visits were used to classify the type of scour at each bridge site into four categories as follows:

- General scour due to adjustment of the river's longitudinal profile to changing flow and sediment load. For the purpose of this study, general scour was considered as scour which is not caused or affected by the presence of a bridge.
- Constriction scour resulting from the raised velocities associated with the reduction in the cross-sectional area of the flow as a consequence of narrow bridge openings. This creates the potential for riverbed scour in the contracted section and immediately downstream of the bridge.
- Local scour resulting from the formation of vortices around bridge foundations such as piers, abutments and other man-made obstructions to the river flow. Local scour is particularly dangerous as it can directly undermine the foundations.
- Outflanking where the approach embankments of a bridge are scoured away.

A fifth category was used in situations where the type of scour could not be identified, or was concealed by water or dense vegetation.

More than one type of scour was evident at most bridges. Particular attention was paid to general, constriction and local scour which directly attack the bridge foundations. Relatively little attention was paid to the erosion of approach embankments, although outflanking is not an uncommon failure mechanism for river crossings. For each type of scour, the percentage of sites at which it was observed was counted to determine its prevalence. In the end, the type of scour could only be accurately identified for 105 of the 121 sites investigated.

3.4 Costs of scour damage

The annual value of current scour damage was mainly estimated from scour repair costs obtained from the provincial BMSs – which are typically updated on 5 year cycles. The contribution of the less frequent major flood events to the annual scour damage cost was much harder to determine, although some of the historical reports indicated total flood damage.

Costs of current scour damage

The scour damage costs presented below reflect the value of damage routinely sustained by South Africa's provincial road bridges in terms of 2005 values. They generally exclude extreme events. It was assumed that the damage was sustained over a 5 year period prior to inspections since bridge inspection and maintenance generally takes place on a 5 year cycle. The total scour repair cost calculated for each province was thus divided by 5 to obtain an annual value. As cost data was not available for every province, various methods were adopted to estimate the total cost for the country.

Reliable repair cost data was obtained from the BMSs for the Eastern Cape, Gauteng and Northern Cape provinces. The cost for scour damage could thus be directly determined from the total value of the repair activities associated fixing it. The percentage of bridges experiencing scour damage and the cost per scour-damaged bridge were then computed (Table 3).

Table 3: Prevalence and costs of scour damage in the Eastern Cape, Northern Cape and Gauteng

Province	Proportion of bridges with scour damage (%)	Cost per scour-damaged bridge (R)
Eastern Cape	26	R 51,000
Northern Cape	20	R 25,000
Gauteng	16	R 3,000

Comprehensive maintenance cost data was obtained for 31 severely scoured bridges in the Free State. The repair component of the total maintenance cost and photographs of the structures were then used to estimate the average scour repair cost of R24,000 for each of the bridges. This is similar to the rate calculated for the Northern Cape. This, however, is likely to be a conservative estimate as the Free State is a wetter province than the Northern Cape. It was also assumed that, as in the Northern Cape, 20% of bridges in the Free State were subject to scour damage.

The costs of scour damage in KwaZulu Natal, Limpopo Province and the Western Cape were partially inferred from the more reliable cost data from the Eastern Cape and Free State. According to the provincial BMS, scour damage is evident at 28% of bridges in KwaZulu Natal. Seeing that the rivers and therefore the bridges in KwaZulu Natal are larger than those in the Eastern Cape, the cost per scour-damaged bridge was conservatively estimated as R57,000 which is only slightly more than that calculated for the Eastern Cape.

In Limpopo Province, it was assumed that 24% of bridges currently experience scour damage and that the average repair cost per bridge is R40,000. These values are intermediate between those for the Free State and Eastern Cape. A rate of R42,000 per scour-damaged bridge was assumed for the Western Cape. It was assumed that 24 % of bridges in the province are subject to scour damage.

The number of bridges in Mpumalanga and the North-West Province were unknown and thus had to be estimated from numbers in neighbouring provinces using land area and population ratios. In Mpumalanga, for example, the number of bridges in the province was estimated as follows:

$$B_{MP} = \frac{1}{2}\left(\frac{A_{MP}}{A_{LP}} + \frac{P_{MP}}{P_{LP}}\right)B_{LP} \qquad (1)$$

The subscripts *MP* and *LP* refer to Mpumalanga and Limpopo Province respectively. *B* is the number of bridges, *A* the area and *P* the population of the province. It was assumed that scour occurs at 24 and 22% of bridges in Mpumalanga and the North-West respectively. The cost per scour-damaged bridge was estimated at R42,000 in Mpumalanga. A value of R27,000 – closer to that in the Free State – was assumed for the North-West Province.

Costs of historical scour damage
Estimates of the repair costs for four bridges which failed during the 1987 floods in Natal were available from the KwaZulu Natal Department of Transport. These are included separately to give an indication of by how much inclusion of extreme events might increase the annual value of scour damage in South Africa. The current (2005) annualised cost of scour damage for a single bridge which failed in 1987, for example, was computed as follows:

$$C = \frac{C_{1987} I}{RI} \qquad (2)$$

C_{1987} was the cost of repairing the work in 1987. *I* is a factor to convert 1987 values to 2005 values. The cost of repairing the bridge in 2005 values is then divided by the recurrence interval *RI* of the flood at the bridge location to get an indication of the annualised repair cost of the bridge, *C*, in 2005 values assuming that the recurrence intervals of the flood and the damage are equal.

4 FINDINGS OF CURRENT SCOUR SURVEY

4.1 Types of scour observed

General scour
General scour was observed at 20% of the 105 bridges analysed. It is often a natural process but may be accelerated by mining of the riverbed. Figure 2 shows a bridge where general scour has exposed piles now subject to local scouring.

Constriction scour
Constriction scour was evident at 44% of the bridges studied and was typically characterised by a lowered riverbed under the bridge and immediately downstream (Figure 3). In some cases, scour caused by constriction was evident for a significant distance downstream. Constriction is also linked to outflanking as a narrow opening will cause excessive afflux, overtopping and erosion of the approach fill. Water which exits a constriction at a high velocity may also cause local scour as backflow occurs against the downstream abutments. Scour at man-made river constrictions aggravates sediment deposition on agricultural land, in dams and on human settlements downstream as occurred in Laingsburg in 1981.

Local scour
Local scour at piers and abutments was found at 60 % of the surveyed sites and was the most prevalent type of scouring identified. Local scour is not usually visible, particularly under flood conditions. Scour holes may also be concealed by turbid water and vegetation which has grown in stagnant pools under bridges. When the field survey was undertaken during July 2004, the east coast and interior of South Africa were experiencing a dry season. Evidence of local scouring could thus be observed in several dry riverbeds (Figure 4) and in shallow, clear water. Local and constriction scour were found to occur simultaneously at 37% of sites. Local scour was observed at piers and at the upstream sides of several abutments where the oncoming flow was not aligned with the bridge openings.

Outflanking
Outflanking of bridges and weirs was not the focus of this investigation but is linked to constriction scour as constriction causes afflux which may overtop earth embankments. Figure 5 shows a bridge which is likely to be outflanked due to lateral migration of the meander on which it is situated.

Figure 2: General scour has exposed pile foundations in the Palmiet River in the main street of Grabouw, Western Cape.

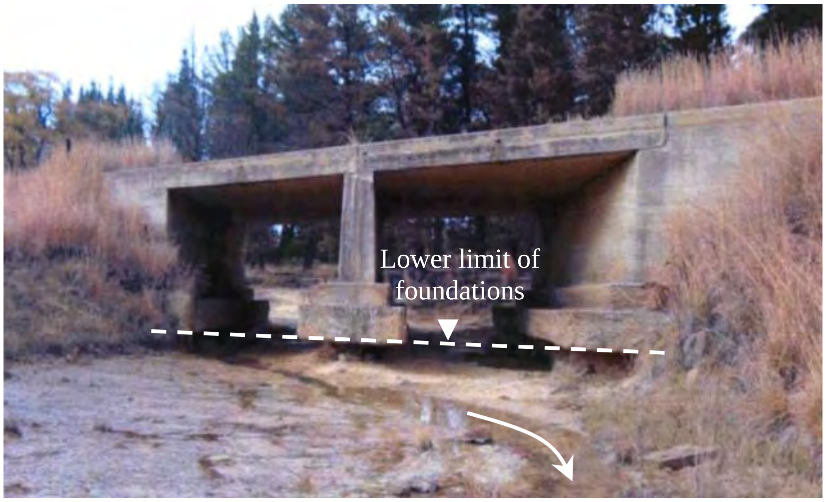

Figure 3: The bridge above is in a critical state as constriction scour has eroded the riverbed under and downstream of the structure, exposing the foundations completely. The foundations rest only on small amounts of directly-compressed material.
(Photo: Free State Department of Transport)

Figure 4: Local scour hole at the Touw River bridge between Ladismith and Riversdale, Western Cape.

Figure 5: Lateral erosion on this meander of the Gouritz River, Western Cape, has shifted the natural river bank quite some distance beyond the bridge abutment. The bridge is in danger of being outflanked in future floods.

Predominant scouring mechanisms and severity of scour problems
The predominant mechanism of scour observed was local scour followed by constriction scour. The prevalence of each type of scour is summarised in Table 4. The table indicates the percentage of structures at which each scour type was evident, but does not provide any indication of the severity of the problem. More than one type of scouring was evident at many sites.

Table 4: Predominance of different types of scour at South African river bridges

Type of scour	Prevalence of scour type (%)
Local	60
Constriction	44
General	20
Outflanking	10

In general the constriction scour observed was considered more severe than the local scour evident, presenting a greater threat to the structural integrity of the affected bridges. The situation might, however, be different during the major flood events which cause catastrophic failure of large bridges. The depth of local scouring under these extreme conditions might well be several orders of magnitude greater than that observed under low flow conditions during the dry season.

4.2 Financial costs of scour damage

Table 5: Estimates of the annual financial value of scour damage

Province	Total number of bridges	Total scour repair cost (R)	Annual scour repair cost (R)
KwaZulu Natal	3200	R 51 100 000	R 10 200 000
Western Cape	2200	R 22 200 000	R 4 400 000
Eastern Cape	1400	R 18 300 000	R 3 600 000
Free State	1800	R 8 800 000	R 1 800 000
Limpopo Province	800	R 7 600 000	R 1 600 000
Mpumalanga	600*	R 6 100 000	R 1 200 000
North-West	650*	R 3 800 000	R 760 000
Northern Cape	500	R 2 500 000	R 510 000
Gauteng	680	R 330 000	R 74 000
Total		**R 120 000 000**	**R 24 000 000**

* Number of bridges estimated

Estimates of the average annual costs of routine scour damage on provincial road bridges in South Africa are given in Table 5. These are intended to indicate the order of magnitude of the value of scour damage rather than to serve as reliable and accurate costs. As expected and suggested by historical records, the area of most concern is KwaZulu Natal. The value of scour damage currently experienced in KwaZulu Natal accounts for some 42% of the total damage in South Africa. As the damage caused by major historical flood events is not incorporated in Table 5, the estimate of R24 million can certainly be considered to be a conservative under-estimate of the total cost of the annual average scour damage to provincial road bridges in South Africa. The figures furthermore reflect only the financial costs associated with repair of the affected structures. Quantification of the economic costs associated with failure of vital transport links would further inflate the values.

The contribution of large-scale bridge failures during extreme flood events to the current scour costs still needs to be quantified. The costs in Table 5 were extracted from BMSs which will not generally reflect the cost of major repair to vital routes by large floods. Comprehensive cost data for historical floods is, however, not readily available. Table 6 gives an indication of the contribution which a large flood event such as the 1987 floods in Natal may make to the annual average cost of scour damage in South Africa. Cost data was available for four of the scour-damaged bridges as listed in the table. A total of 120 bridges in Natal were, however, destroyed or severely damaged in this flood event (Van Bladeren & Burger, 1989). Thus a single large flood event may add many millions of Rands to the effective annual average scour damage costs, easily increasing the value of scour damage to way beyond R30 million per annum.

Table 6: Selected bridge repair costs for the 1987 floods in Natal

Bridge (River)	Cost (Rm) 1987	Cost (Rm) 2005	Flood recurrence interval*	Annual scour cost (Rm)
John Ross (Tugela)	6.0	33.5	45	0.7
Scottburgh (Mpambanyoni)	3.0	16.8	33	0.5
Josephines Bridge (Mkomaas)	2.0	11.2	200	0.1
Batstones Drift (Mzimkulu)	1.0	5.6	70	0.1

* Kovács (1988)

5 CONCLUSIONS

Scour damage is generally associated with extreme flood events. A study of current scour damage at road bridges in South Africa has indicated that, whilst severe scour damage – sufficient to threaten the structural integrity of the bridges – is seldom observed under “normal” flow conditions, scour damage is common. Evidence of severe scouring during past floods was, however, seen at several sites.

Routine scour damage to provincial road bridges in South Africa averages in the order of R24 million per annum. About 42% of this cost is attributed to scour damage in KwaZulu Natal. This cost excludes the damage incurred in extreme flood events and the economic costs associated with the disruption caused by the failure of major transport links. Inclusion of the financial costs of scour damage during extreme floods will easily inflate the average annual scour cost beyond R30 million.

Local and constriction scour are the two scouring mechanisms occurring most frequently at bridge sites. Local scour was observed at 60% of the 105 bridges investigated in detail, whilst constriction scour was observed at 44% of them. The severity of the constriction scour observed in the field study was generally greater than that of the local scour, and thus it could be that excessive constriction of the flow poses the greater threat to South African river bridges. This assessment may however be invalidated when extreme flood events such as the 1984 and 1987 floods in Natal are considered. The local scour occurring at large bridges during these floods would surely be far more severe than that observed in this study at smaller bridges in the dry season. Unfortunately, local scour is hard to measure compared with constriction scour as the scour hole is rapidly filled after the passing of the flood peak.

Local scour is a priority for research into scouring at river bridges in South Africa as the actual effects of this mechanism under flood conditions are unknown, cannot be observed and the damage is often concealed by sedimentation after the event. The combined effects of local and constriction scouring also require attention as this combination was observed at 37% of the sites investigated.

6 RECOMMENDATIONS

A review of the causes of failure of major bridges during extreme floods is necessary. This will give a better indication of the type of scour damage causing the failure of major structures which is of more concern than ongoing damage to smaller bridges on less important routes. Future investigations should focus on KwaZulu Natal as the costs associated with scour damage in this province are estimated to account for 42% of the total value of scour damage in South Africa – which is a consequence of its generally high mean annual precipitation and the large number of bridges. The study should also be extended to include pipe and rail bridges, weirs and other hydraulic structures.

The costs associated with scour damage to bridges on the National Roads must be estimated. This should include the economic costs associated with the disruption of major transportation and service routes in order to obtain a better reflection of the true costs.

Further research in local scour is necessary as the severity of scour resulting from this mechanism under flood conditions is unknown and very difficult to measure. Local scour was also identified as the most prevalent form of scour damage observed at road bridges during this study. Research into the combined effects of constriction and local scouring is also justified.

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